GCM Parameterization Challenges At High Latitudes

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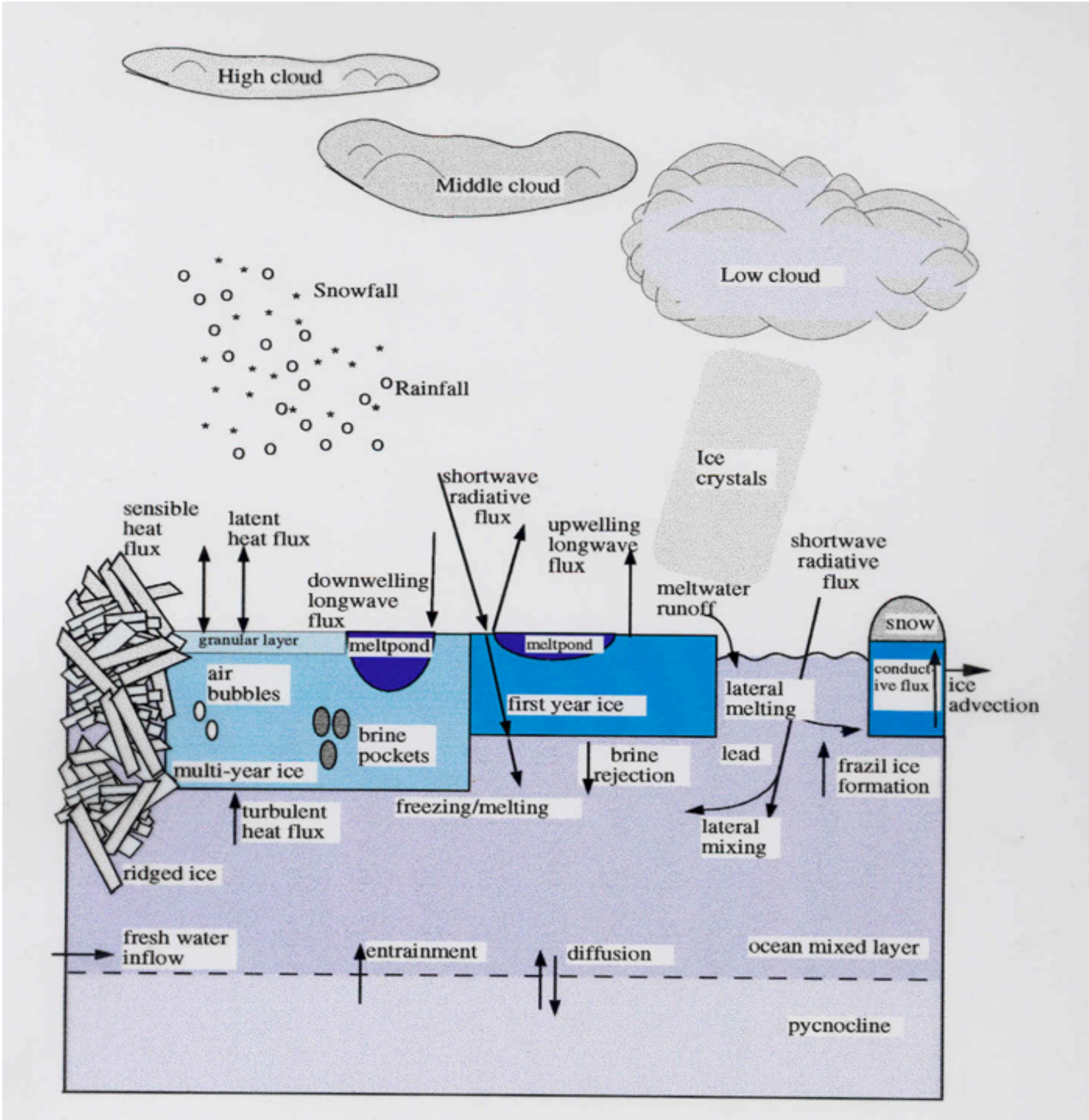

High cloud
Middle cloud
Low cloud
Snowfall
Rainfall
Ice crystals
shortwave radiative flux
sensible heat flux
latent heat flux
upwelling longwave flux
downwelling longwave flux
meltwater runoff
shortwave radiative flux
snow
granular layer
meltpond
meltpond
conductive flux
ice advection
air bubbles
first year ice
lateral melting
brine pockets
lead
brine rejection
multi-year ice
frazil ice formation
turbulent heat flux
freezing/melting
lateral mixing
ridged ice
fresh water inflow
entrainment
diffusion
ocean mixed layer
pycnocline

Radiative Transfer

The clear-sky radiative transfer is essentially solved

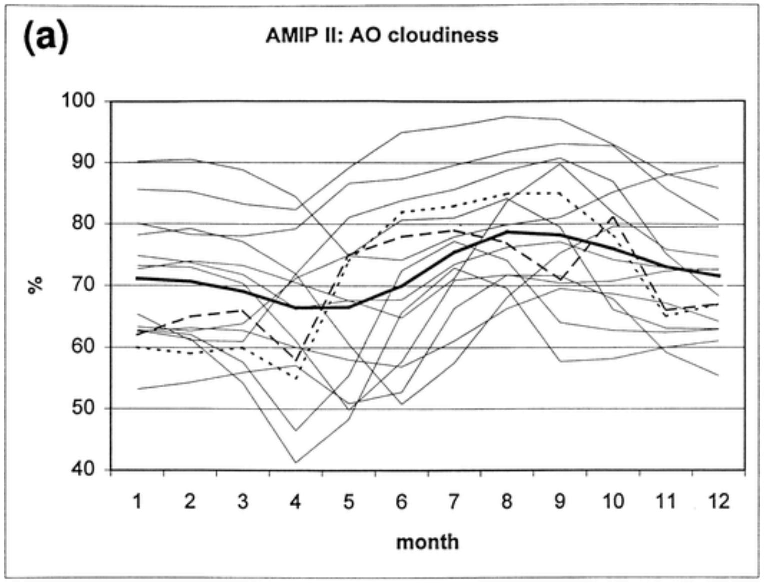
- major breakthrough from SHEBA (“dirty window”)

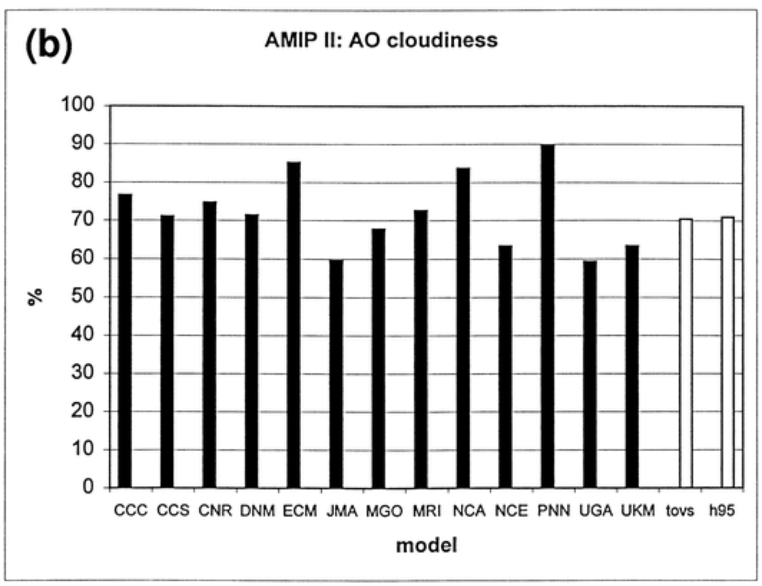
Remaining issues:

- cloud overlap (CloudSat and Calipso should help) ❖
- consistency between microphysics code and r.t. code in specifying cloud optical properties ❖
- correct handling of the highly reflecting surface
- (3D radiative transfer NOT a big issue in the polar regions)

❖ Good target for NASA MAP

Representation of Arctic Clouds in Models





- Atmospheric Model Intercomparison Project (AMIPII).
- Annual cycle is vaguely captured, though several are out of phase.
- Large variability between models.

From Walsh et al. (2002)

Possible reasons for poor simulations of Arctic clouds

Poor large scale dynamical fields

Inadequate boundary layer parameterizations

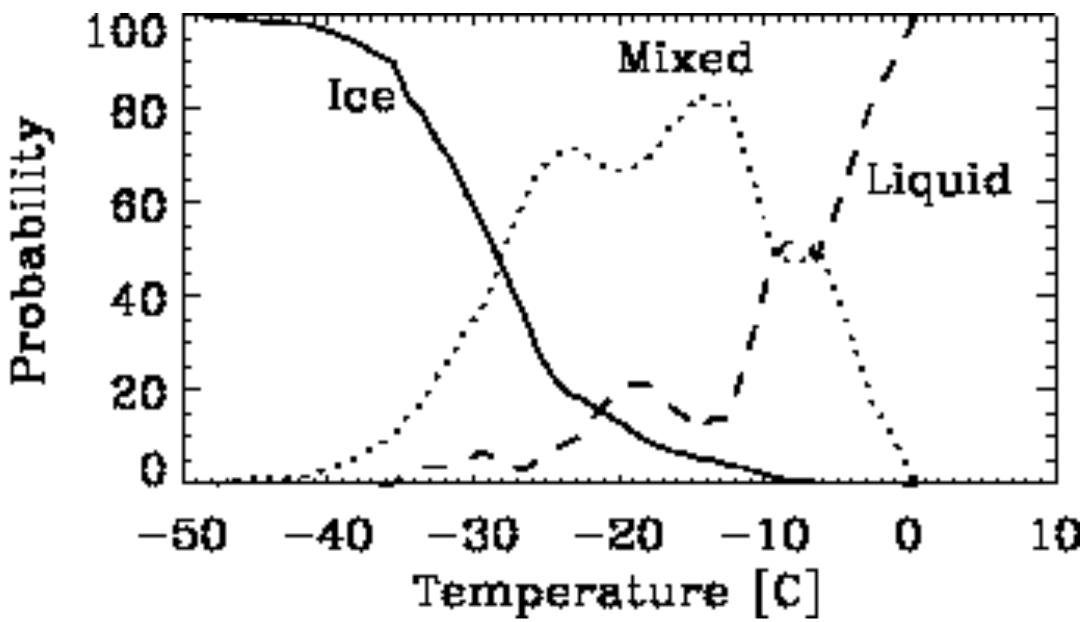
Incorrect surface temperature and surface state

❖Inadequate cloud microphysical parameterizations

Inadequate vertical resolution

Etc.

Arctic Cloud Microphysics: Cloud Phase is the Dominant Issue



- At -30C, more than half the clouds have liquid
- Cloud phase has a substantial impact on radiative fluxes and precipitation

Dual Moment Bulk Microphysical Models

Microphysical elements that need parameterizing ❖:

- Liquid drop nucleation
- Ice particle nucleation
- Diffusional growth
- Liquid droplet size spectra
- Ice crystal size spectra
- Fall speed
- Particle collection and aggregation
- Subgrid-scale supersaturation fluctuations

Key issue is to get the microphysical elements interacting correctly with the aerosols to produce the correct indirect effect and getting new parameterizations into GCMs

Boundary Layer Parameterizations

Existing B.L. parameterizations work poorly in the Arctic, owing to:

- Static stability and strong temperature inversions
- Persistent negative surface heat fluxes
- Large-scale subsidence
- Mixed phase and crystalline clouds
- Wintertime convection in leads

Result in

- Incorrect vertical profiles of T, q, u
- Incorrect clouds
- incorrect surface fluxes

Issues: boundary layer

To do list:

- Prognostic equation for b.l. height accounting for subsidence
- Investigation of missing mechanism in TKE generation; LES studies of breaking waves in steep inversions
- Thermodynamics for b.l. crystalline and mixed phase clouds ❖
- Observations of surface fluxes and b.l. evolution over wintertime leads ❖

❖ Good target for NASA MAP

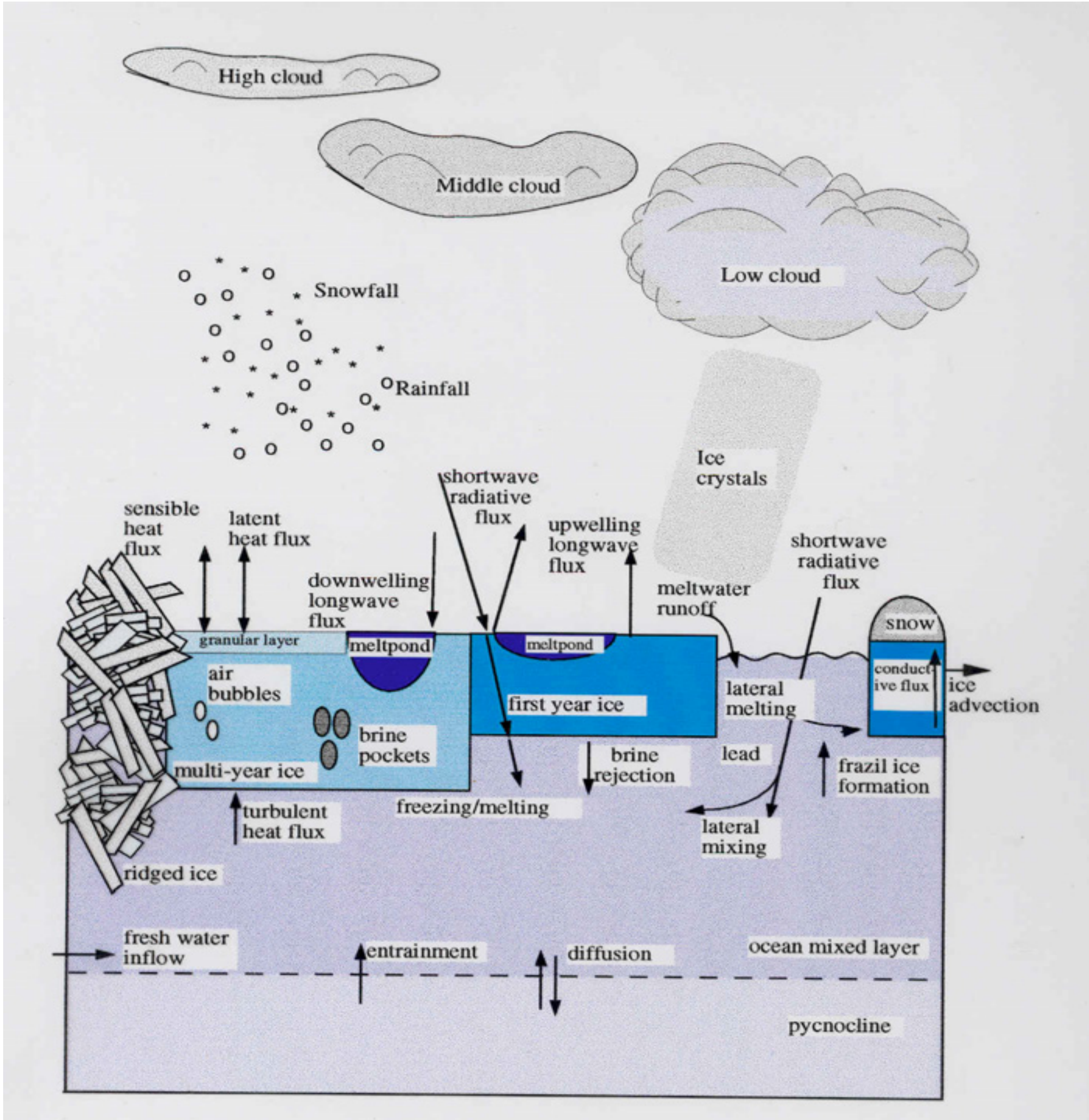
Sea Ice Modeling

Sea ice feedbacks are complex:

- internal sea ice processes
- ❖interactions with local atmosphere and ocean
- interactions with global processes

Current sea ice models and parameterized interactions with the atmosphere and ocean are likely to be inadequate at simulating the climate in an altered sea ice regime.

❖ Good target for NASA MAP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But what about SHEBA?

SHEBA observations:

✓thermodynamical and optical properties and processes

✓exchanges at ice/atm and ice/ocean interfaces

8 years after the SHEBA field experiment, none of these observations have influenced new parameterizations in sea ice models used in GCMs

Late breaking development: spectral delta-Eddington parameterization of sea ice optical properties
(Briegleb & Light) will be incorporated in NCAR CCSM

Needed Improvements to Sea Ice Models

- Spectral radiative transfer: surface albedo, transmission through snow, sea ice, upper ocean. ❖
- Explicit melt ponds: albedo, latent heat, salinity effects ❖
- Snow:nonlinear conduction, metamorphism, redistribution ❖
- Ice age: optics, thermal conductivity, specific heat, etc. ❖
- Formation of snow/ice
- Frazil ice formation
- Ice deformation: brine rejection;enhanced decay of ridged ice
- Lead width distribution: lateral melting, turbulent fluxes ❖
- Ice/ocean turbulent flux for ice thickness distribution ❖
- Fast ice: detailed ocean bathymetry,granular rheology

❖ good observations from SHEBA

Summary of parameterization issues

Mostly solved issues:

- radiative transfer
- surface turbulent fluxes over ice/snow

Issues ripe for major progress in short term

- cloud microphysics and interactions with aerosols ❖
- cloud overlap ❖
- sea ice optics (and thermodynamics) ❖
- (cross-talking parameterizations) ❖

Issues limited by observations:

- turbulent fluxes over leads ❖
- new ice formation, coastal sea ice, ridges ❖

Issues limited by physical understanding:

- stable boundary layer
- cloud-turbulence interactions
- heterogeneous ice nucleation ❖

❖ Good target for NASA MAP